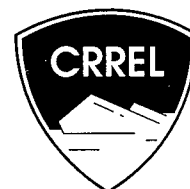
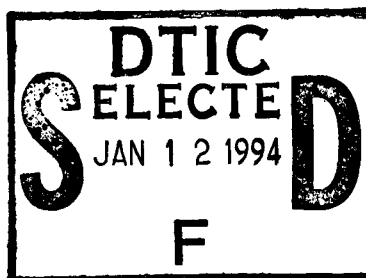


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CRREL REPORT



Design and Evaluation of a Towed Snowplow for the Small Unit Support Vehicle (SUSV) Full-Scale Prototype Development and 1992 Field Tests

Paul W. Richmond and Michael R. Walsh

October 1994



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Abstract

Light Infantry Division elements require a system to allow them to conduct semi-autonomous operations and limited self-resupply with existing wheeled vehicles in snow deeper than 15 cm. Since many roads and trails will not have been kept open prior to deployment, truck-mounted plows (if available) would be ineffective. In most instances, heavy tracked vehicles, which can cause extensive environmental damage, are required to move deep snow. Over-snow vehicles can be equipped with front- or rear-mounted plow blades. But to adapt a plow to the U.S. Army's only over snow vehicle, the small unit support vehicle (SUSV), would require major vehicular modifications. A towed plow assembly for the SUSV was proposed. To adapt the plow for this application, a unique four-bar parallel linkage towing assembly was developed, which bolts directly on to the SUSV's pintle hook mounting bracket. This assembly controls the pitch, and the plow geometry stabilizes the roll of an attached plow. The plow was constructed primarily of aluminum, has three plowing widths, and can be towed over the road (minimum width 2.3 m). This report describes the design, operation and results of field tests of the towing assembly and plow. The SUSV successfully towed the plow through deep (85 cm) unbonded snow, creating a path wide enough for a wheeled vehicle. In hard, dense, wind-blown snow the plow was less successful, requiring several passes to open a trail. No major failures occurred, although some minor problems were identified, and recommendations for design improvements are presented.

Cover: Path (2.5 m wide) up small hill in hard, dense snow in Bolio Lake area of Ft. Greely, Alaska. The SUSV with the plow is in the background.

For conversion of SI metric units to U.S./British customary units of measurement consult *Standard Practice for Use of the International System of Units (SI)*, ASTM Standard E380-89a, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.



**US Army Corps
of Engineers**

Cold Regions Research &
Engineering Laboratory

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PREFACE

This report was prepared by Paul W. Richmond of the Applied Research Branch, Experimental Engineering Division; and Michael R. Walsh of the Engineering Resources Branch, Technical Resources Center, U.S. Army Cold Regions Research and Engineering Laboratory. This study was funded under DA Project 4A762784AT42, *Design, Construction and Operations Technology for Cold Regions*, Work Unit CS/008, *Mobility Concepts for Light Forces*.

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This report was technically reviewed by Sally A. Shoop, Research Civil Engineer, Applied Research Branch; and Paul V. Sellmann, Geologist, Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, CRREL.

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Design and Evaluation of a Towed Snowplow for the Small Unit Support Vehicle (SUSV) Full-Scale Prototype Development and 1992 Field Tests

PAUL W. RICHMOND AND MICHAEL R. WALSH

INTRODUCTION

Light Infantry Division elements require a system to allow them to conduct semi-autonomous operations and limited self-resupply with existing wheeled vehicles in snow deeper than 15 cm. Only one vehicle available to these elements, the small unit support vehicle (SUSV), is capable of maneuvering in deep snow. Since many roads and trails will not have been kept open prior to deployment, truck-mounted plows (if available) would be ineffective because of the volume of snow to be moved. In most instances, slow-moving heavy-tracked vehicles, which can cause extensive environmental damage, are required to move deep snow. Over-snow tracked vehicles similar to the SUSV have been equipped with front- or rear-mounted plow blades, but to adapt an existing plow to the SUSV would require major vehicular modification.

The most effective solution to the problem of creating vehicular access paths through deep snow was to pull a plow behind the SUSV. A towed plow, rather than a pushed plow, was considered most feasible because towed plows tend to lift and ride up over an obstacle instead of digging into the ground. Small-scale (1:12) testing of several models indicated that a V-plow modeled on a concept proposed by Price (1966) would be the most effective in terms of efficiency and stability. Pitch control problems, resulting in the plow plunging or riding up, needed to be solved before incorporating a plow of this design into the system. A novel four-bar, parallel-linkage towing assembly was developed, which bolted on to the SUSV's pintle hook mounting bracket and attached to the plow nose. This assembly effectively controls the pitch of an attached plow while allowing freedom of motion in the roll direction.

A study was conducted to evaluate the feasibility

of the towed-plow concept by examining the performance of a half-width version of the plow (Walsh and Richmond 1992). Design parameters for a full-scale plow are discussed in that report. The available drawbar force for the SUSV is 23 kN in deep snow (> 0.6 m), although 13.4 kN was considered a reasonable design constraint based on the average available drawbar force during tests conducted by Murrell and Shumate (1989). Analysis of the results obtained during this study indicated that a drag plow capable of clearing a 2.45-m-wide path in 1-m-deep, low-density snow would require a drawbar force of approximately 13 kN on level terrain, 97% of the average available tractive force in deep snow.

This report describes the design, operation and results of field tests of the towing assembly and full-width plow. The SUSV successfully towed the full-scale plow through deep, unbonded snow (85 cm max), creating a path in one pass wide enough for a wheeled vehicle. In hard, dense, windblown snow the plow was less successful, requiring several passes to open a trail. No major failures occurred, although some minor problems were identified, and recommendations for design improvements are presented.

PLOW CHARACTERISTICS AND DESIGN DETAILS

The full-scale plow shares many features with the half-width model. Primary among these is the four-bar linkage towing mechanism (Fig. 1). This mechanism attaches to the SUSV pintle mount through an adapter (Fig. 2). The four-bar linkage consists of a tractor link, two towing links and a plow link.

The tractor link attaches to the pintle mount adapter through a central pivot stub axle, which

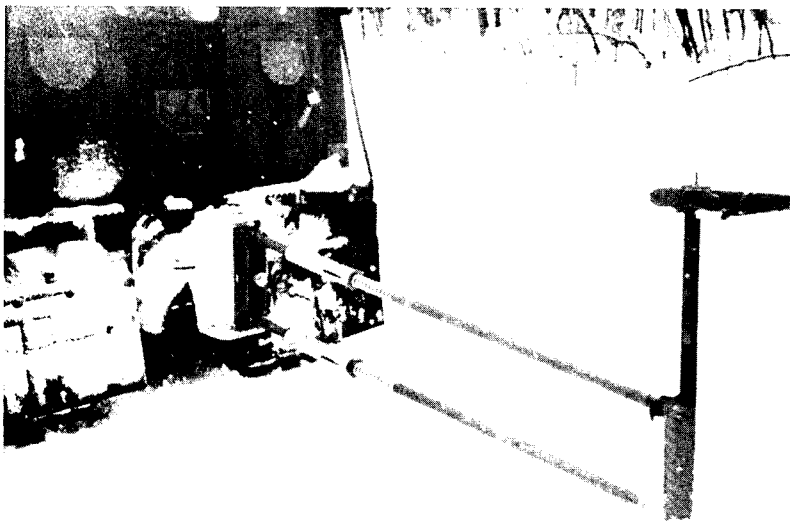


Figure 1. Four-bar towing linkage.

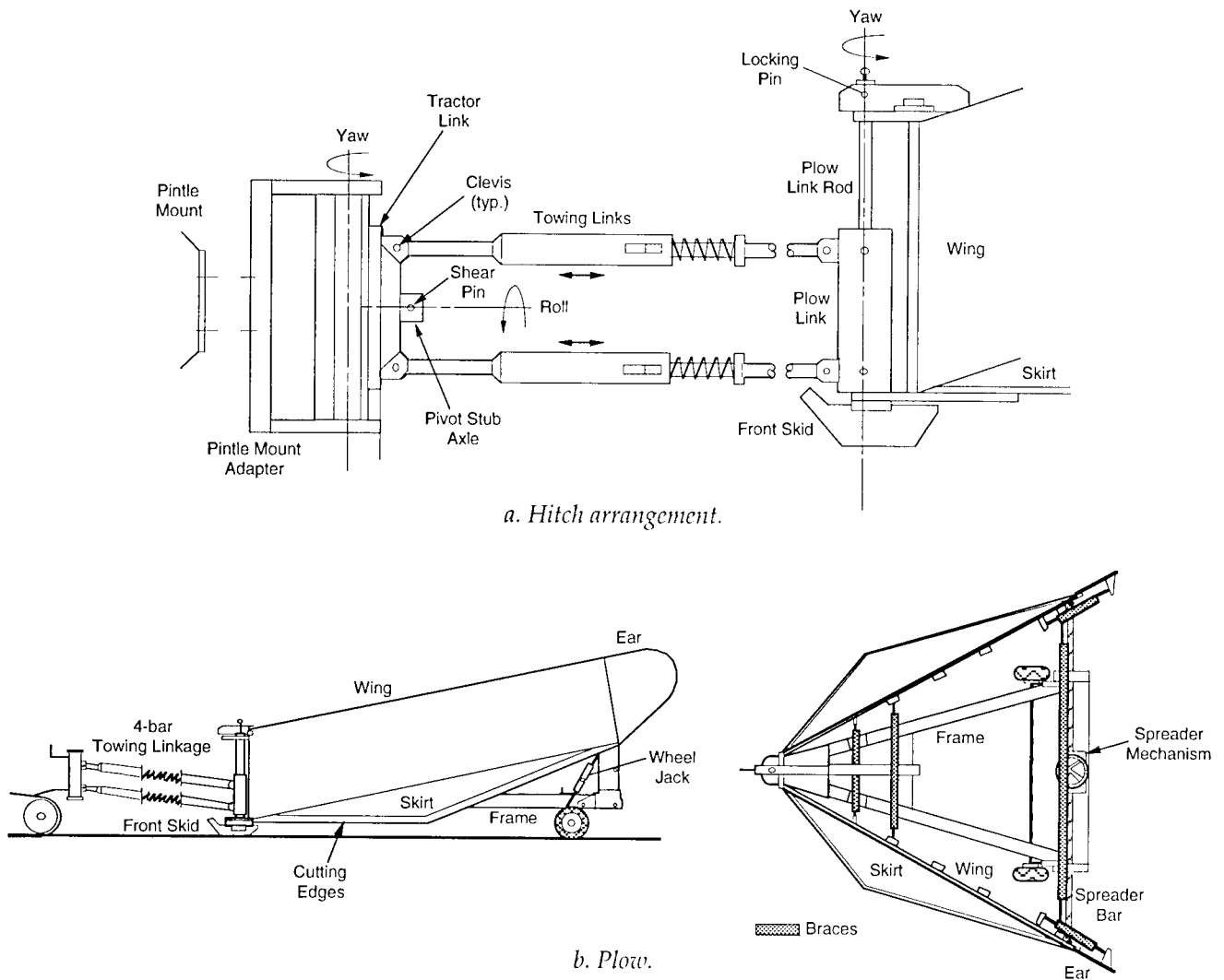


Figure 2. Schematic of plow and hitch.

allows the plow to roll in the axis of the SUSV. In addition, the adapter pivots in the vertical axis (yaw), which allows the plow to follow directly behind the SUSV in both the towing and plowing configurations. Attachment of the tractor link to the adapter is through a shear pin, designed to fail at 41 kN, safely below the maximum drawbar capacity of the SUSV (49 kN). The tractor link has two clevises located 30.5 cm apart for attachment of the upper and lower towing links.

The plow link is an adjustable block attached to the plow. Like the tractor link, it has two clevises mounted 30.5 cm apart to accept the towing links. The plow link is vertically adjustable in 15.25-cm increments to adapt the towing mechanism to varying snow conditions. The total adjustment range is 45.75 cm. The pivoting plow link rod, to which the plow link is mounted, is attached rigidly to the front plow skid. The plow link pivots in bearings mounted at both ends of the rod. This feature, along with the parallel rotating axis on the tractor link, allows the plow to track directly behind the SUSV. For road transport (discussed later in this report), the plow link is locked to eliminate rotation. The plow and tractor links are parallel when the equipment is on a flat surface.

The final two components of the towing mechanism are the towing links, which attach to the plow and tractor links. The towing links are 1.75 m in length, which allows sufficient vertical travel between the rear of the SUSV and the plow for operations in deep snow. These links are longer than the ones used on the half-width model and solved some of the vertical control problems attributed to the 1.25-m links on the half-width model. The plow links have a spring-loaded section that allows the plow to ride over a 16-cm obstacle without overstressing the mechanism. Their lengths can be adjusted to control pitch and to facilitate mounting and attachment of the four-bar towing mechanism to the SUSV.

The V-plow is constructed primarily of welded aluminum with steel cutting edges and with a

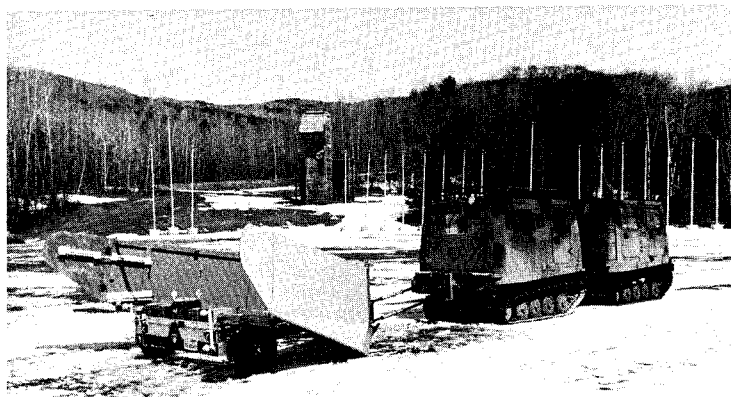


Figure 3. Full-scale prototype plow mounted to the SUSV.

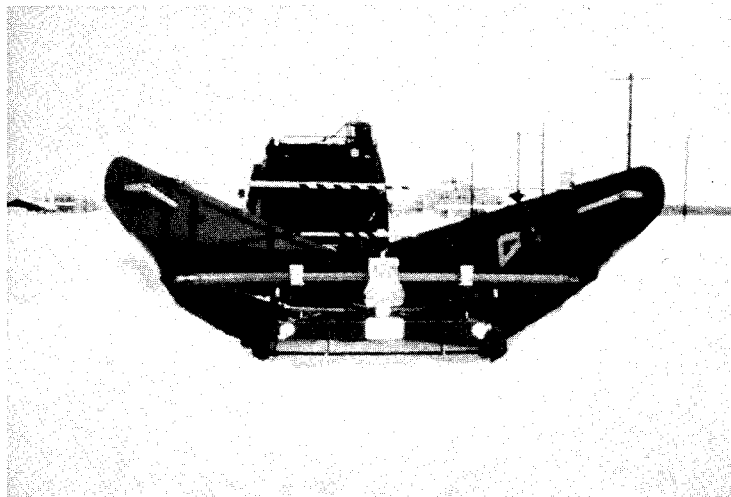


Figure 4. Rack-and-pinion spreader mechanism.

covering of ultra-high-molecular-weight polyethylene (UHMW PE) on the plowing surfaces (Fig. 3). Borland (in prep.) investigated possible plow coatings and found UHMW PE to be the best coating tested for this application. The plow is designed to ride on three points: a front skid and the two rear wheels. Three plowing widths are available (measured at the wing ends): 2.1 m (fully closed), 3.1 m (half opened) and 4.1 m (fully opened), corresponding to angles of 30°, 45° and 60°. The wings are hinged at the plow nose, and a manually operated rack-and-pinion spreader mechanism (Fig. 4) is used for adjustment. The maximum plowed path width in 1 m of snow is 2.4 m. Bracing in several locations is used to keep the plow blade stable during transport and use. Wing extensions (ears) fold in to facilitate shipping.

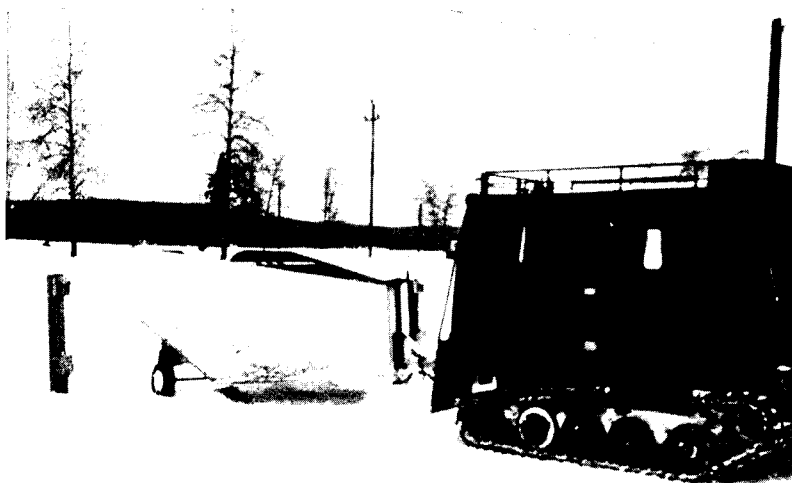
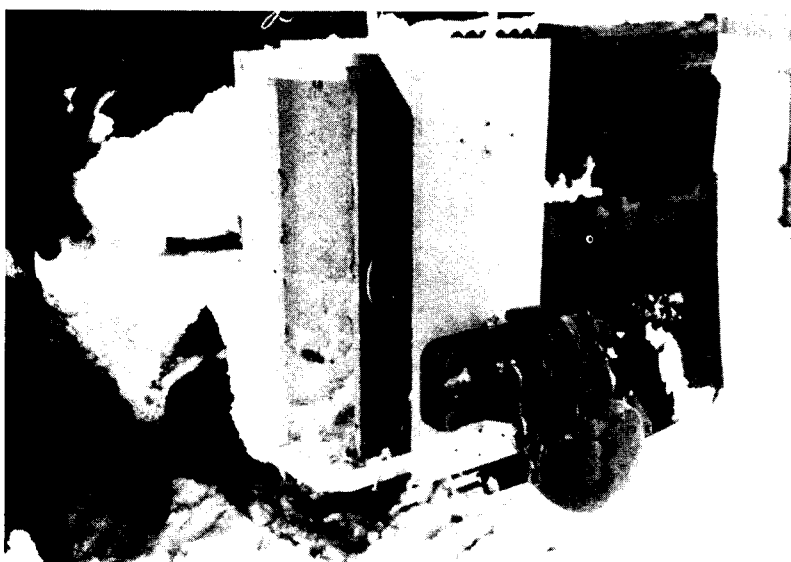
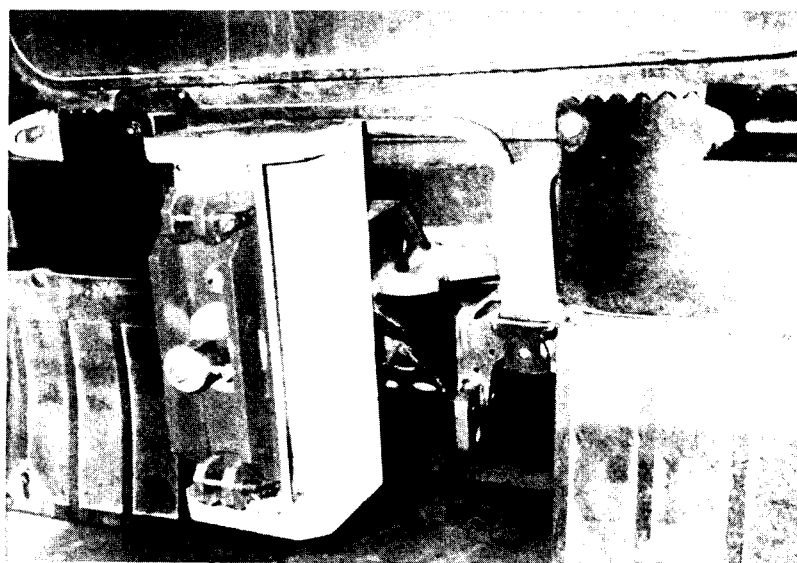


Figure 5. Road transport configuration.



a. Pintle hook adapter.



b. Pintle mount adapter.

Figure 6. Pintle adapter.

PLOW OPERATION

A primary design parameter for the towed snowplow was that it require no modification to the towing vehicle. All aspects of the plow—over-the-road transport to actual operation—are designed to be independent of the tractor except for the use of the tractor's towing capacity. All adjustments to the plow are done manually.

Transporting the plow to the point of deployment is an important aspect of the plow operation. The plow can be transported with any vehicle equipped with a pintle hook and trailer light receptacle. During transport on the road, the wings are fully closed, and the ears are folded and locked in the transport position (Fig. 5). The long cross brace is stored in its retracted length on the inside of the left wing of the plow. The upper central cross brace (Fig. 2) is attached to the rearmost of the three clevises for this brace. To prepare the plow for transport, both rear wheels are chocked, and the upper and lower towing links are removed and stored at the rear of the plow. The towing adapter, stored on the right rear wing, is attached to the plow link, using the two clevises. This link must be at the lowest adjustment point for jacking and towing. Also, the plow link rod must be locked with the $\frac{3}{8}$ -in. pin provided.

The pintle hook adapter is then attached to the pintle mount adapter on the back of the SUSV (Fig. 6). The pintle eye is raised to the level of the pintle hook using the integral jack on the towing arm. The SUSV is then backed up to the pintle eye on the towing arm, and the connection is made. The pintle hook is closed and locked, the jack lowered, and the weight of the front of the plow is taken by the pintle. The rear wheels are lowered to increase ground clearance. The towing safety chains are attached, the rear lights connected, the chocks removed and stored, and the plow is ready for transport. The plow has been towed at speeds in excess of 95 kph over well-maintained roads. High speeds on rough roads are not advisable, as the plow does not have an adequate suspension system to handle the impact forces and displacements encountered under these conditions.

Upon arrival at the point of deployment, the plow is readied for operation. With the plow parked in a level, easily accessible location, the rear wheels are chocked and the nose jacked until the weight of the plow is removed from the pintle. The wiring harness is disconnected, and the tractor pulled away from the plow. The plow is lowered, and the towing arm is removed and stored on the right wing. The two towing links are installed, and the

pintle adapter is removed and stored (if towed with the SUSV). The rear wheels are raised until about 15 cm of clearance is left under the leading edge of the plow skirt. If the off-road access is blocked by a steep or hard snowbank, it is advisable at this time to form a path with the SUSV before the plow is attached. This will greatly reduce the forces on the towing mechanism. The plow link rod locking pin is removed, and the two towing links are attached to the tractor link of the SUSV, using the adjustment in the towing links to compensate for any misalignment.

Terrain, snow depth and snow conditions will dictate how wide an area can be plowed. In light ($\sim 0.2 \text{ Mg/m}^3$) snow, up to 1 m deep, on level terrain, the plow can be operated in the fully opened position. If the terrain is hilly, with grades in excess of 15%, and the snow is deeper than 0.5 m, it is advisable to plow at half width and later open the path to full width. For extremely difficult conditions, such as the hard, dense snow ($> 0.45 \text{ Mg/m}^3$) encountered at Ft. Greely, it may be necessary to operate in the fully closed position. Performance at these widths and under various conditions will be discussed later in this report.

To plow in the fully closed position, the plow is configured in the same manner as when it is transported over the road. The only difference is that the ears are swung out and locked in the plowing position; deploying the ears is optional, especially in areas where snow depths are less than 0.7 m. Operating the plow in the closed position, rather than in the half-open position, only marginally decreases drawbar forces, as will be shown later. Therefore, it is recommended that the plow be used in the closed position only if the plow becomes stuck while in the half-open position.

To open the plow to the half-open position, the upper central cross brace is removed and the rear of the plow spread using the rack-and-pinion mechanism (Fig. 4). With one end of the long brace attached to an upper rear clevis, the plow width is adjusted until the other end is in position and locked to the opposite clevis. The central cross brace is then installed into the center set of clevises (in the middle of the plow), and the spreader arms are locked in place. The ears should be deployed when plowing in half-open or fully open conditions. The exception to this rule would be in locations of shallow snow or confined areas.

In the fully open position, the plow is cranked all the way open with the long brace still attached but not pinned in the middle. The long brace and spreader arms are pinned when the locking holes

in the long brace align. The central cross brace should now fit into the forward set of clevises in the middle of the plow. To close the plow up from either opened position, the central cross brace is removed, the rear long brace is unlocked or removed, and the spreader bars are unlocked and cranked shut. In situations where the plow is stuck, it may be necessary to shovel off the wings to unload them. Otherwise, it may not be possible to unlock the spreader bars or remove the clevis pins from the braces.

Plowing was carried out with the SUSV generally in low range to maximize available torque and therefore drawbar capacity. Terrain and snow conditions again dictated plow operations, with successful plowing carried out in third gear of low range and first gear of high range. At higher speeds, there is a tendency for the plow to ride up due to an increase in vertical force on the nose of the plow. In denser snow conditions, it was found that raising the plow link increased the penetration of the plow. This was as expected from an analysis of the forces in the towing mechanism. Raising the link decreases the towing angle, resulting in a decrease in the vertical force on the plow nose, making it more aggressive in the hard-packed snow.

FIELD TESTS

The plow was tested between 13 and 26 February 1992, primarily at Fort Wainwright, Alaska. On 24 February the plow was towed to Fort Greely, Alaska, for two days of testing. The objectives of these tests were to determine the plowing capabilities of the SUSV and the reliability of the plow and hitch assemblies and to identify any operational problems.

Four test areas were used at Fort Wainwright. Three of the areas were flat and generally covered with undisturbed snow. These are identified as the shop field, the airport field and the Tanana River firing range. A ridge of blown snow was encountered at the airport field, and multiple plowed access roads were crossed at the firing range. The fourth area, Chena field, contained a depression with a 20% slope, and the area had been subjected to extensive snowmobile traffic. In general, the snow was 60–90 cm deep and was not well bonded. Snow pit data from the Fort Wainwright test areas are given in Figure 7. Table 1 contains a summary of all the snow data obtained during tests.

Table 1. Summary of average snow conditions, 1992.

Test location/Date	Pit number	Depth (cm)	Avg density (Mg/m^3)
Ft. Wainwright			
Shop Field			
13 February	1	67.5	0.295
13 February	2	71.5	0.189
13 February	3	See Figure 7	
13 February	4	65.0	0.192
14 February	1	67.0	0.192
14 February	2	68.0	0.179
14 February	3	70.0	0.186
15 February	1	67.0	0.202
Chena Field			
20 February	1	70.0	0.205
Airport Area			
22 February	1	69.0	0.220
Ft. Greely			
Drop Zone			
24 February	1	78.0	0.379
Bolio Lake			
25 February	1	62.0	0.294

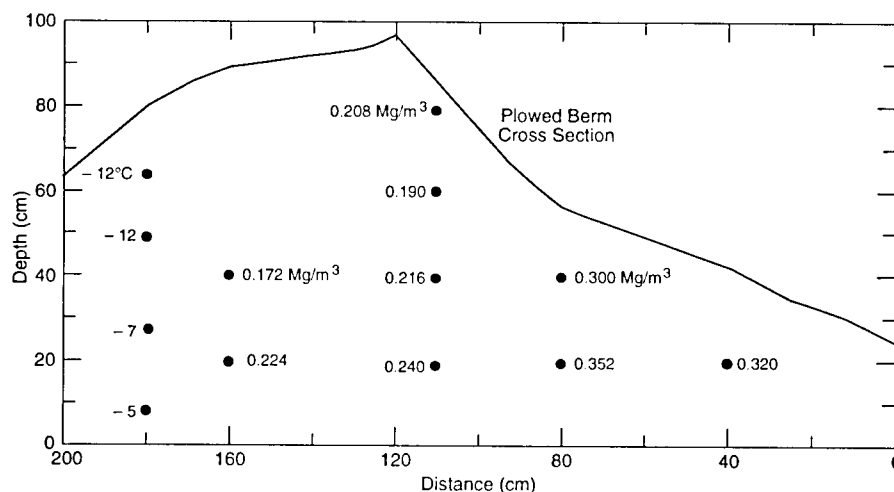


Figure 7. Snow characteristics at Ft. Wainwright.

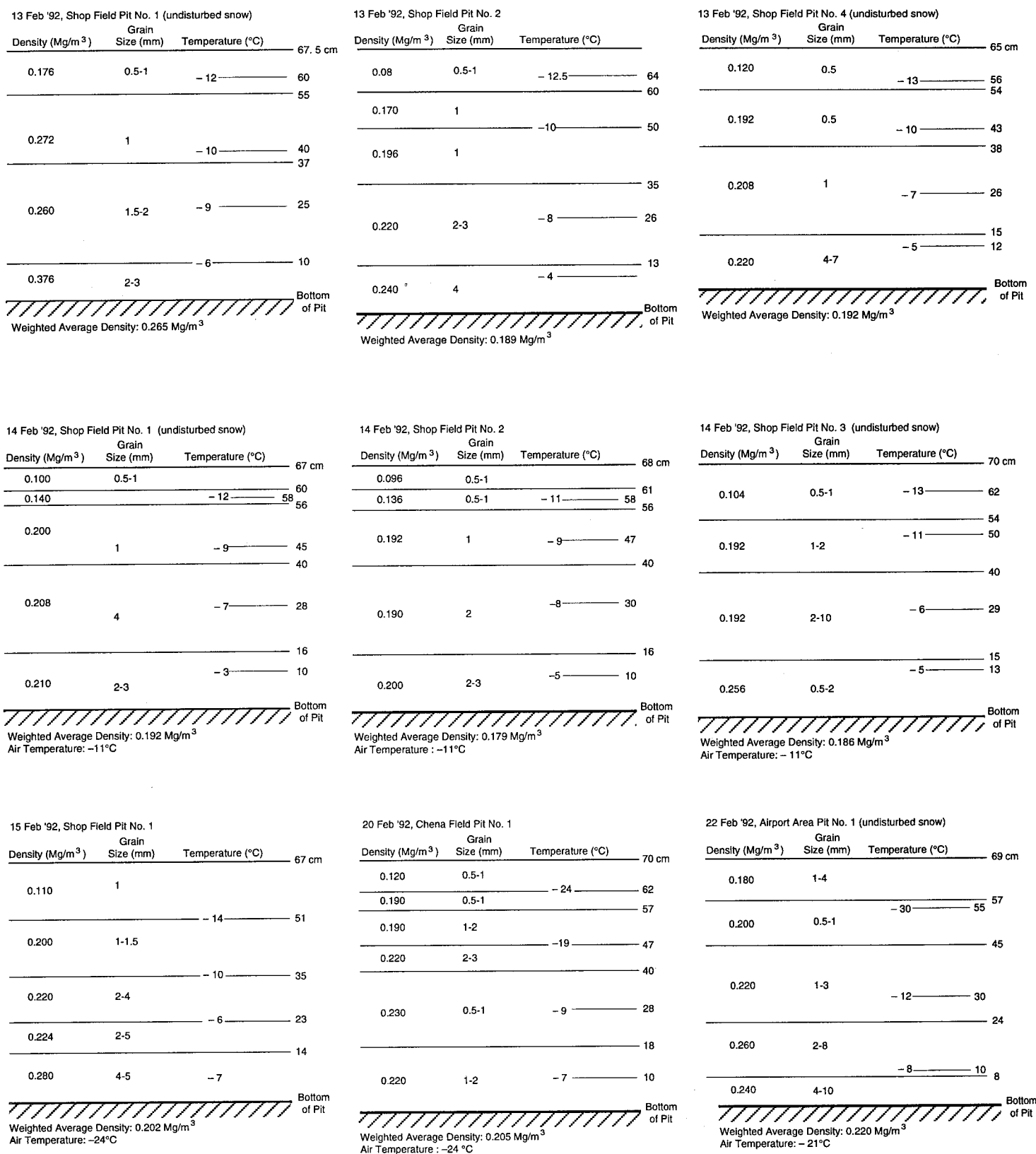


Figure 7 (cont'd).

24 Feb '92, Drop Zone, Pit No. 1			
Density (Mg/m ³)	Grain Size (mm)	Temperature (°C)	
		- 10	78 cm
0.432	0.5-1		
		- 14	
			34
0.320	1-3	- 9	
			17
0.300	1-2	- 8	
			Bottom of Pit
Weighted Average Density: 0.379 Mg/m ³			
Air Temperature: 0°C			

25 Feb '92, adjacent to Bolio Lake Rd. (undisturbed snow)			
Density (Mg/m ³)	Grain Size (mm)	Temperature (°C)	
0.280	1	- 6.5	62 cm
			52
0.328	0.5-1	- 8	
			40
0.380	0.5-1.5	- 9	
			29
0.280	1-3		20
			10
0.240	2-6	- 6	
			Bottom of Pit
Weighted Average Density: 0.294 Mg/m ³			
Air Temperature: 6°C			

Figure 8. Snow characteristics at Ft. Greely.

Three test areas were used at Fort Greely. The snow depth varied from 0 to 1.2 m and was wind blown, hard packed and very dense. Snow drifts were hard and dense enough so that in many places the SUSV did not break the surface, and at higher speeds with the plow link in the lowest position, the plow did not dig into the snow on the first pass. Snow characteristic data for Ft. Greely are in Figure 8 and Table 1.

Over-the-road tests, except for a few around the shop area used to obtain baseline drag data, were informal and primarily resulted from moving from one test area to another or from the shop to the test area. Additionally, the plow was towed from Fort Wainwright to Fort Greely (350-km round trip) using a Chevrolet Suburban with a 1200-kg-capacity hitch. The maximum speed on this trip was 96 kph. Towing distances and maximum speeds are given in Table 2.

A set of measuring and recording instruments were installed in the rear unit of the SUSV used at Ft. Wainwright so that various vehicle and plowing variables could be recorded (Fig. 9). A detailed description of the instrumentation is reported in Walsh and Richmond (1992) and Osborne (1991). Table 3 presents a list of the variables measured

Table 2. Stiff hitch towing of plow.

Configuration	Distance (km)	Maximum speed (kph)
Towed by SUSV: On base	31	40
Towed by SUSV: Off base	77	48
Towed by Suburban	350	96

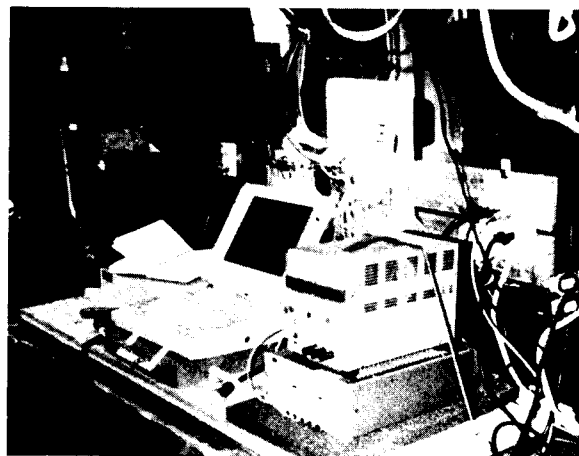


Figure 9. Test instrumentation and data acquisition system.

Table 3. Test instrumentation.

Variable	Device	Location
Drawbar force (kN)	Sensotec load cell, 44.8-kN capacity	Top and bottom links of four-bar linkage
Tilt (°)	Lucas AccuStar electronic clinometer, $\pm 60^\circ$ range	Interior of rear SUSV unit and top link of four-bar linkage
SUSV speed (kph)	Micro-Trak Trak-Star, ultra-sonic speed sensor	Front of SUSV, with digital display for driver and input to digital counter in the data acquisition system

and the measuring devices used in these tests. The analog data were multiplexed and digitized using an Elexor PL-1000 data acquisition system controlled by a laptop computer. Data were stored on the laptop's internal hard drive for later analysis. Electrical power was supplied by a 2.2-kW generator strapped to the roof of the SUSV rear unit. The only significant change from the instrumentation package described by Walsh and Richmond (1992) was the replacement of the tilt sensors.

PLOW PERFORMANCE

Plow performance can be interpreted a number of ways. In this section we describe performance by reporting the forces required to pull the plow through snow, the difficulties encountered in operating the plow, and the repairs and modifications made to the plow during the field tests. Initial tests were conducted using narrow (1.25-cm) steel skids as the rear supports. These quickly proved inadequate and were removed. Further tests were conducted using the road wheels as the rear supports.

Towing forces

Towing forces were analyzed by determining the horizontal and vertical components of force in each of the towing links and summing the component values for both links. The angle measured by the tilt sensor on the top link was used to determine the components. Figure 10 shows that the values reported are always in reference to true vertical and horizontal regardless of the SUSV attitude. For comparison be-

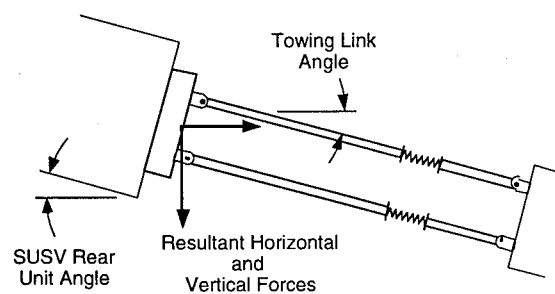


Figure 10. Relationship of reported force components.

tween tests, this simplification affects only those tests on significant slopes. Almost all the tests were conducted on level terrain, and for these tests the horizontal and vertical component values represent the towing resistance and

tongue load to the SUSV, respectively. A summary of the measured forces is given in Table 4. Richmond and Walsh (1993) contains a complete set of data plots and descriptions of these tests. In these data, negative force values represent resistance to towing (horizontal component) or a downward load (vertical component). Occasionally, positive component values occurred during testing. These values were attributed to either slight bouncing of the plow over surface irregularities or the relative

Table 4. Data summary 1992 SUSV plow tests.

Date	Test no.	Horizontal forces (kN)		Vertical forces (kN)		Velocity (kph)	Plow position
		Max	Avg	Max	Avg		
Ft. Wainwright: Shop area—Skids							
13 Feb	0213A01	-5.2	-0.1	-0.7	< -0.1	4.8	Closed*
13 Feb	0213B01	-5.6	-0.7	-0.9	-0.1	4.8	Closed*
13 Feb	0213C01	-3.8	-0.5	-0.4	< -0.1	5.0	Closed*
13 Feb	0213C02	-18.1	-5.0	-4.5	-1.1	1.0-6.7	Closed
13 Feb	0213D01	-19.4	-10.0	-7.5	-2.1	0-6.1	Closed
13 Feb	0213D02	-19.9	-6.3	-3.5	-1.1	1.0-6.1	Half open
13 Feb	0213D03	-22.6	-9.2	-6.5	-1.7	1.6-7.4	Half open
13 Feb	0213E01	-20.8	-8.0	-4.4	-1.6	0-7.7	Half open
14 Feb	0214A01	-3.9	-1.7	-0.6	-0.2	5.0	Half open
14 Feb	0214A02	-3.4	-1.3	-0.5	-0.2	5.0	Half open
14 Feb	0214A03	-25.5	-10.4	-4.5	-1.7	0-5.8	Half open
14 Feb	0214A04	-14.9	-7.9	-3.3	-1.8	2.2-6.7	Closed
14 Feb	0214A05	-11.2	-5.4	-3.1	-1.3	1.0-5.6	Closed
Ft. Wainwright: Shop area—Wheels (skids removed)							
14 Feb	0214A06	-3.4	-0.7	-0.8	-0.1	5.0	Closed*
14 Feb	0214A07	-11.3	-5.5	-3.8	-1.7	0.6-7.0	Half open
14 Feb	0214A08	-9.4	-5.9	-4.2	-1.9	5.0	Half open
14 Feb	0214B01	-12.5	-6.7	-3.9	-1.8	5.4	Fully open
14 Feb	0214B02	-10.3	-7.0	-3.9	-2.1	5.6	Fully open
14 Feb	0214B03	-16.3	-6.2	-7.5	-1.9	5.6	Fully open
Ft. Wainwright: Airport Field—Wheels							
15 Feb	0215C01	-10.5	-7.1	-3.6	-2.5	0-5.3	Fully open
15 Feb	0215C02	-15.4	-9.0	-5.5	-3.2	0-5.4	Fully open
15 Feb	0215C03	-18.9	-9.1	-4.6	-2.8	0.3-7.7	Fully open
15 Feb	0215C04	-14.2	-5.3	-4.6	-1.6	0.6-7.0	Fully open
15 Feb	0215C05	-12.5	-9.6	-4.2	-3.2	3.7	Fully open
15 Feb	0215C07	-9.9	-6.4	-3.7	-1.9	1.6-5.4	Fully open
Ft. Wainwright: Chena Field—Wheels							
19 Feb	0219A01	-7.1	-1.1	-1.5	-0.2	5.1	Fully open*
19 Feb	0219A02	-15.0	-7.8	-4.8	-2.3	0-7.7	Fully open†
20 Feb	0220A01	-14.2	-8.1	-4.2	-2.5	0-7.7	Fully open
20 Feb	0220A02	-10.1	-5.9	-4.2	-1.8	1.9-6.7	Half open
20 Feb	0220A03	-11.9	-4.6	-4.4	-1.2	0.3-8.0	Fully open
Ft. Wainwright: Tanana River Firing Range—Wheels							
21 Feb	0221A01	-14.2	-7.2	-4.6	-2.0	0-8.0	Fully open
21 Feb	0221A02	-18.1	-9.5	-5.9	-2.8	0-8.3	Fully open
21 Feb	0221A03	-11.6	-5.8	-2.8	-1.6	5.1	Fully open
Ft. Wainwright: Airport Field—Wheels							
22 Feb	0222A01	-8.1	-6.3	-2.6	-1.9	5.0	Fully open
22 Feb	0222A02	-5.8	-4.6	-2.5	-1.5	4.9	Half open
22 Feb	0222A03	-7.2	-4.3	-2.1	-1.2	4.9	Closed
22 Feb	0222A04	-10.5	-8.9	-3.4	-2.6	4.8	Fully open
22 Feb	0222A05	-9.8	-7.0	-2.9	-1.7	9.8	Fully open
22 Feb	0222A06	-12.2	-9.2	-3.9	-2.7	2.6	Fully open
22 Feb	0222A07	-12.4	-6.8	-4.1	-1.8	2.6-7.4	Fully open

* Test conducted on hard-packed snow road.

† Stopped on slope; lost shear pin and instrumentation cables.

orientation between the rear SUSV unit and the plow as they pass through low spots in the terrain.

13 and 14 February 1992

Tests were conducted on the road surrounding the CRREL shop and an adjacent field (the shop field) located near the northwest corner of the airfield at Ft. Wainwright. The objectives were to examine the plow tracking performance using the rear skids, check out the instrumentation and do some initial plowing. The most significant results of these two days of testing began with test 0214A03. This test began on the road with the plow half open. The plow was pulled through an area previously plowed with the plow half open, and then an attempt was made to break out of this path through a hardened, sintered bank into an undisturbed area. Here the SUSV became stuck and the highest resistance value (for all tests) was recorded (-25.5 kN, or -5705 lb). The plow was changed to the fully closed position, and with no further assistance the SUSV continued through the undisturbed area. Testing continued with test 0214A04 and 0214A05.

At this point it was decided to remove the rear skids and use the wheels to see if the resistance

during plowing would be lower. Observations made during previous tests indicated the rear skids were embedding themselves 4–5 cm into the coarse gravel surface of the shop field. Experiments with the half-width version indicated that the plow would not dig down into dense snow if the wheels were used to support the plow during plowing. Plow penetration, stability and plowing resistance were all variables monitored during these tests.

Test 0214A06 was a baseline test on the hard-packed shop road with the wheels supporting the rear of the plow. The average resistance was much less than the resistance obtained with the skids on the same road earlier that day [-0.65 kN (-146 lb) vs. -1.48 kN (-332 lb)]. Test 0214A07, with the plow half open, followed the half-opened path plowed earlier and broke through a hardened bank into an undisturbed area without difficulty. There was no noticeable increase in the plowing resistance as this breakthrough occurred, although a momentary drop in velocity was recorded.

At this point the plow was opened to full width, and tests were done without difficulty. A commercial four-wheel-drive pickup truck was driven around this full-width path without difficulty (Fig. 11). Cross sections of the full-width plowed area are given in Figure 12 and are probably representative of these test conditions only, as many factors will influence these dimensions.



Figure 11. Pickup truck driving in a plowed path.

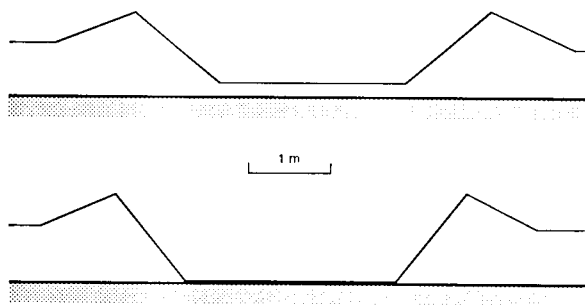


Figure 12. Cross sections of plowed paths.

15 February 1992

No significant observations were made on this day. The tests were all conducted at the airport field, which consisted of a grassed area adjacent to an unplowed area of the runway and an unplowed asphalt taxiway. During test 0215C07, a partially successful attempt was made to widen the previously plowed path. The plowing resistance values for undisturbed snow in this area averaged about -8.9 kN (-2000 lb) for the undisturbed snow portions of tests 0215C02, 0215C03 and 0215C05.

19–20 February 1992

Tests on these days were conducted in the Chena Field area. In test 0219A03 the shear pin holding the tractor adapter to the pintle adapter broke, resulting in the failure of the instrumentation cables. The pin, a low-strength, mild-steel clevis pin, was replaced with the proper type and plowing continued. An attempt was made to climb a relatively long hill. The plow became stuck, so it was closed to the half-open position, and plowing up the remainder of the hill continued. With the instrumentation repaired, test 0220A01 was an attempt at the same



Figure 13. Vehicle parked at the base of a plowed slope.

hill with the plow fully open. The SUSV again became stuck, and the data indicate that the slope was about 12° (20%) when the SUSV stopped. The snow depth was about 76 cm. It should be noted that in deep, dry, loose snow, as we encountered here, the maximum gradeability for the SUSV alone is 30%. The plow was closed to the half-open position, and the SUSV was able to continue up the hill (test 0220A02). Test 0220A03 was a replot of this lane with the plow fully open. Figure 13 shows a four-wheel-drive vehicle parked at the base of the slope. The tilt sensor data for the rear SUSV unit (Fig. 14) indirectly indicates the slope angles encountered during these tests.

21 February 1992

Tests on this day were conducted on one of the Ft. Wainwright firing ranges. These tests were significant because they were done in the roughest ground conditions tested. This location, which we called the Tanana River firing range, is located 13.9 km from our base of operations at the CRREL garage. The plow was towed to the firing range with the SUSV at a maximum speed of 50 kph. The snow was primarily undisturbed except for plowed access paths located about every 0.2 km leading to targets. These paths were perpendicular to the path plowed during the tests. The terrain under the snow was rough and contained bulldozed brush, as well as stumps and logs. The recorded data (tests 0221A01–0221A03) showed no large forces on the plow, although forces were not recorded during the entire time snow was being plowed. Plowing was generally done in low range,

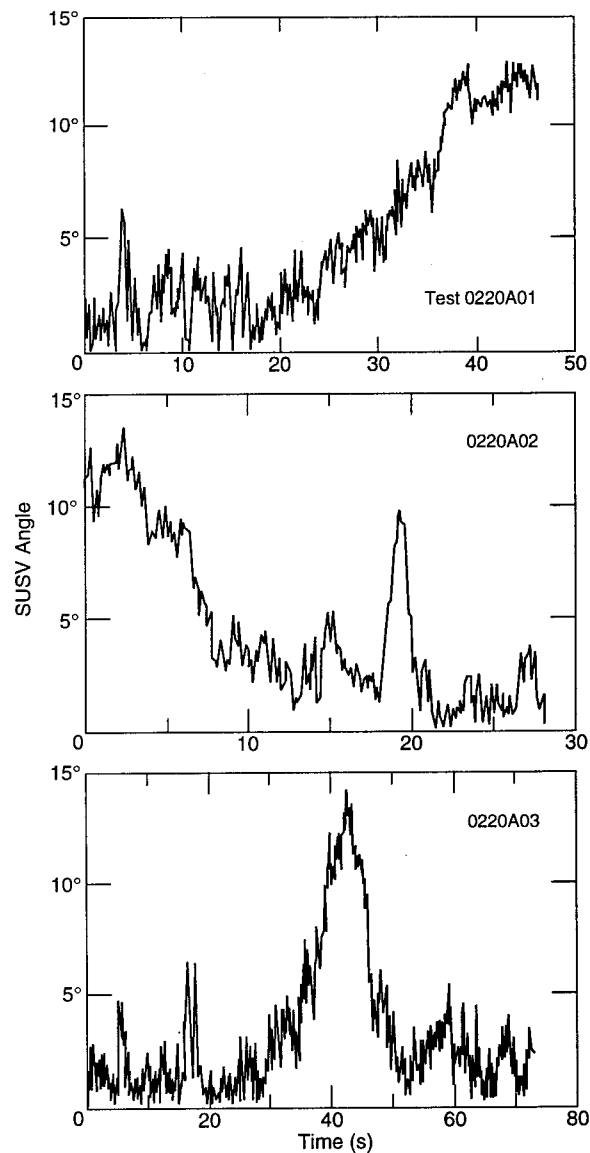


Figure 14. SUSV angle on a slope.

second gear at a speed of about 9 kph. Plowing was done with the plow fully open, and some damage to the plow occurred. The damage consisted of a broken weld where the left wing is attached to the pivot for opening and closing the plow.

22 February 1992

Tests on this day were conducted at the airport field. The objectives of these tests were to measure the effect of plowing a track that had previously been trafficked by SUSVs and to determine the difference in towing forces obtained at the three plowing widths in undisturbed snow. First, an undisturbed area was driven over five times using the SUSV without the plow attached. This area was allowed to harden or sinter for about one

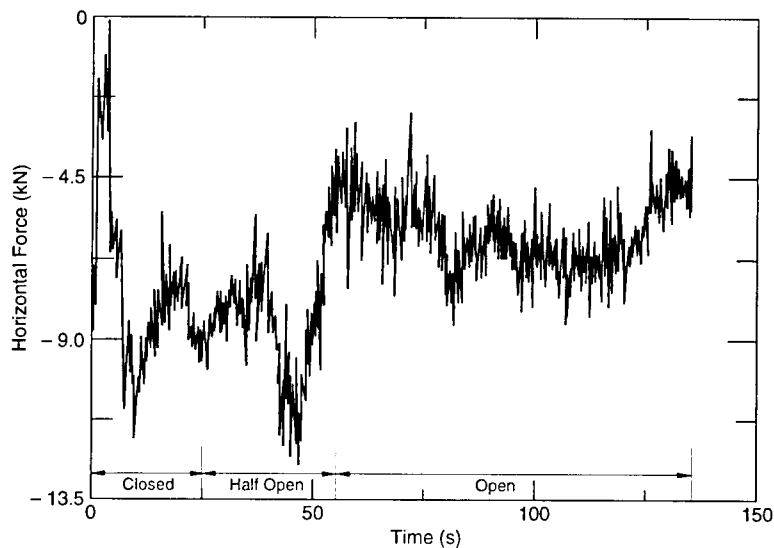


Figure 15. Horizontal forces during plowing of a previously plowed path at three widths.

hour. While this area was hardening, a series of tests (0222A01–0222A03) were conducted with the plow fully open, half open and closed. Data were recorded after the SUSV reached a speed of about 4.8 kph (3 mph) and was in a previously undisturbed area. These tests indicate that, as expected, towing resistance decreases as the plow is closed. Closing the plow from fully open to half open reduced the resistance by about 1.69 kN (380 lb), or about 27%. Fully closing the plow further reduced the resistance by 0.29 kN (65 lb), or about 6%. The reduction in resistance of only 0.29 kN (65 lb) between the half-open and closed positions seems low compared to the reduction between the fully open and half-open positions. The frontal widths or forward projections of the plow in the three positions are 4.1, 3.1 and 2.1 m for the fully open, half-open and closed positions, respectively (wings only). Included plow angles for the three positions are 60°, 45° and 30°, respectively, for the wings. The only apparent cause for the small reduction in force between the half-open and closed plow drawbar forces is the influence of the plow skirt. When the plow is fully opened, the ratio of skirt width to wing width is 0.73. For half-open and closed positions, the ratios are 0.84 and 1.01. While the wings tend to displace the snow laterally from the towing axis, the skirts lift and laterally displace the snow, a process that requires more force. As the skirts become the more dominant factor in snow displacement, the reduction in force due to closing the plow may become less. There were no other similar tests that could be compared to these to verify this pattern.

Tests 0222A04–0222A06 were conducted on the area compacted by the SUSV earlier. The resistance

obtained in tests 0222A04 and 0222A06 is about 2.67 kN (600 lb) more than that obtained in 0222A01 (undisturbed snow, plow fully open). These tests were done at 4.8 kph (3 mph) and 2.4 kph (1.5 mph), respectively. The resistance of test 0222A05 was about the same as test 0222A01, but the speed was about 9.6 kph (6 mph), suggesting that operating at higher speeds may reduce plowing resistance. Test 0222A07, the last test in this series, was a replowing of the path used for tests 0222A01–0222A03. Replowing the path from the closed-position segment to the full-width segment showed that the resistance decreases as the previously plowed width increases (Fig. 15). There doesn't appear to be a noticeable difference in forces between replowing the segment plowed at half width and replowing the segment plowed at the closed width. This is similar to the data for the variable-width plowing tests described above and may help explain the apparent discrepancies in the differential forces at the three widths.

24–25 February 1992

During this period the plow was towed 175 km from Ft. Wainwright to Ft. Greely to test the plow in significantly different snow conditions. At Ft. Greely the plow was attached to a Cargo-version SUSV (Fig. 16). This SUSV had a six-cylinder engine as opposed to the SUSV used at Ft. Wainwright, which had a five-cylinder engine. It is not believed that these differences greatly affected performance. An additional difference was the height of the adapter hitch above the ground: on the Ft. Wainwright SUSV the adapter was mounted 59 cm above the ground so that the rear door of the SUSV could be



Figure 16. Plow attached to a cargo version of the SUSV, Ft. Greely.

opened; at Ft. Greely the adapter was mounted 78 cm above the ground. This changed the angle of the towing assembly by 6.4° and the drawbar efficiency from 99% to 97%. No plowing resistance measurements were made, as the instrumentation was not brought to Ft. Greely because of time constraints. All transport of the plow at Ft. Greely was done with the SUSV.

Limited testing was conducted on the edge of an open field (drop zone), 5.3 km from the main base, where snow had blown up against a tree line. Snow characteristic data for this site are in Figure 8. In this area the snow was measured as deep as 78 cm. However, it was hard enough to walk on and, as can be seen in Figure 16, the SUSV did not always sink in the snow. This made plowing difficult, as the plow would not always dig into the snow or, conversely, in soft places, the SUSV and plow would sink and become stuck. After the plow was closed, the SUSV extracted itself. Driver inexperience contributed to the problems encountered this day, as plowing was conducted at high speed in high range, exacerbating the tendency of the plow not to penetrate the surface of the snow. It was believed that, even at high speed, with enough passes a plowed path could have been opened up to wheeled vehicles. However, lowering the towing speed would have greatly improved the effectiveness of the plow. Another way to improve plow performance in this hard, dense snow would have been to raise the plow link to decrease the uplift on the nose of the plow.

On 25 February 1992, plowing was done in two areas, the first located off the Richardson Highway on an unplowed access road to a Ft. Greely train-

ing area, 20.3 km from the main base. Here the snow was similar to that encountered on 24 February but may have been deeper in spots. Prior to deployment the plow link was raised 15 cm (one hole) to make the angle of the towing mechanism closer to that of the tests at Ft. Wainwright. Although the plow penetrated the snow cover much better, the SUSV and plow became stuck more often. This may have been caused by the deeper snow drifts. The SUSV and plow were extracted using snow shovels.

The second area in which plowing was done was on a trail in a forested area (near Bolio Lake). Here the snow had not been compacted as much by wind, although snow characteristics were very similar to those at the other two sites (Fig. 17). Open areas had as little as 20 cm of snow, whereas in protected areas, snow drifts were as deep as en-



Figure 17. Terrain at the Bolio Lake test site.

countered elsewhere. The SUSV and plow became stuck only once in this area, while climbing out of a drifted-in hollow at the beginning of testing. Because the snow was relatively dense, it took several passes to open the trail (it was not tested with a wheeled vehicle), with several passes made at each of the plowing widths. The overall performance of the system was much better than at the previous two sites. It was clear at the end of these tests that driver experience was critical in marginal plowing conditions such as these.

Plowing capabilities

The overall performance of the plow in the snow conditions for which it was designed was quite good. In the deep, low-density snow found at Ft. Wainwright, no problems were encountered on level terrain once we switched from skids to wheels on the back of the plow. Crossing hardened snowbanks and breaking out of previously plowed paths did not create obstacles for the plow. Climbing a moderate hill (20% grade) required two passes, one half open and one fully open. The loss of tractive effort of the SUSV was more the cause of this problem than the increased drag force due to plowing uphill. The increased slope added ~3% to the drawbar force of the SUSV, while the loss of traction due to the slope may have decreased the tractive effort by over 50%. As mentioned previously the maximum gradeability for the SUSV in these conditions is 30%.

Plow capabilities in the extremely dense snow of Ft. Greely were limited. Full-width plowing can be ruled out in most circumstances, and multiple passes at half width may be necessary in the worst conditions. Experience is critical when attempting to operate in these snow conditions, and it would be prudent to scout any route before attempting to plow it. A device for breaking up the snow before plowing may be necessary to enable efficient use of the plow in these conditions.

Field failures and repairs

A number of components failed or were damaged during field tests at both facilities. The one outright failure, that of a mild-steel shear pin on the tractor link, was actually encouraging as it proved that the shear pin load limiting concept worked. It should be noted that the mild-steel pin that failed was much weaker in shear than the pins used throughout most of the tests, and that no further failures occurred. The pin was replaced in the field and testing continued.

A number of welds cracked during testing, but again, none halted testing. The most significant

failure was along the left wing pivot bar, where about half the weld was cracked and the base of the wing pulled away about 3 cm (Fig. 18). This was repaired at the motor pool at Ft. Wainwright after completion of that day's testing. Damage was also sustained to the cutting edges at that time. Soil and wood jammed between the cutters and the skirt, forcing the blade out about 1 cm between anchoring screws. Excess debris was removed and testing continued. Another weld failed on one of the supporting outriggers for the rack and pinion. This also did not affect testing and was repaired later in that day after testing.



Figure 18. Broken welds on the plow structure.

Modifications

A number of modifications were made to the plow as a result of testing experience. The most significant was the removal of the skids. This had several impacts on testing: baseline loads were much lower, drawbar forces were much lower, ease of use increased, and plow weight decreased. Several safety shear pins were enlarged, including those for the front skid and the plow link rod lockup pin. These changes greatly improved system reliability. A locking pin was added to the spreader mechanism after an initial test indicated that it would be necessary.

Problem areas that needed to be addressed included wear on the skids, wheel-to-skid conver-

sion, the towing assembly and the spreader mechanism. With the removal of the rear skids, the skids-to-wheels conversion and rear skid wear problems disappeared. The front skid wear problem persists, and a redesigned front skid has been constructed. Further testing will be necessary.

The towing mechanism, although functional, was difficult to use in two respects: the jacking mechanism was quite stiff, and attaching the towing arm to the lower clevis point on the tractor link was almost impossible. The attachment problem was solved by modifying the towing arm to incorporate a pintle eye and designing a pintle hook adapter for the pintle mount adapter on the SUSV. This system was successfully tested at Ft. Wainwright and was thus incorporated in the operations section of this report. The current modification to the jacking mechanism was not as successful and will need further consideration in the next design phase.

The spreader mechanism as designed was not robust enough for this application. Although it performed adequately, a number of persistent problems exist. The major problem was inadequate stiffness. At the fully open position, the ends of the spreader bars sagged at least 4 cm. Lack of stiffness in the plow axis was a problem during opening and closing of the plow, as the bearing points at the end of the bars would stick on the end slides and bind. This was partially the fault of the end slides, which also need to be redesigned. Binding due to alignment problems within the spreader mechanism was also a problem that will need to be addressed in future designs. Finally, a better position-locking design is needed.

The use of the rubber-backed UHMWPE proved adequate in this design. Bubbles that had formed after applying the material to the aluminum plow surfaces, indicative of debonding, disappeared at the low temperatures encountered in Alaska. Differential coefficients of thermal contraction were probably responsible for this. No additional debonding was evident as a result of our tests.

Finally, the wings and ears need to be better braced to eliminate large-amplitude shaking during plowing. Cross bracing of the wings should eliminate the problem with the wings, while a stiffer connection at the ears will be necessary to reduce their flapping. Modifications of weak points in the current design, such as the wing pivot area and the skirt cutter blade design, are being made. All these modifications will be incorporated into the next prototype design.

CONCLUSIONS AND RECOMMENDATIONS

The concept of pulling a V-shaped drag plow behind a SUSV to clear off-road access trails in deep, low-density, unbonded snow is feasible. One of the more interesting findings was that the plow operated much more efficiently in loose snow with wheels as rear plow supports rather than skids. This differed from conclusions drawn from previous tests with a half-width model. Differences in snow conditions, as well as the skids' tendency to penetrate the ground surface, are the probable reasons. In the hard-packed, dense snow of Ft. Greely, plow performance was not adequate, with results similar to those seen with the smaller model under similar conditions. A standard operating procedure needs to be developed for the use of the plow in hilly terrain or other difficult conditions such as those found at Ft. Greely.

Plowing a previously tracked and hardened SUSV path indicated an increase of drawbar force of about 40% over plowing an untracked area. A significant decrease in drawbar pull, over 25%, was found between plowing at full width versus half width. Closing the plow further to the fully closed position decreased the total force less than 10%. The hill-climbing capacity of the system is limited by the gradeability of the SUSV. On the 20% slope the available drawbar force was 10.2 kN, about 40% of the value obtained for level terrain. This is better than the estimated decrease due to grade, about 69%. One possible solution to climbing grades would be to prepack the path with a SUSV without a plow and then attempt to plow a full-width path.

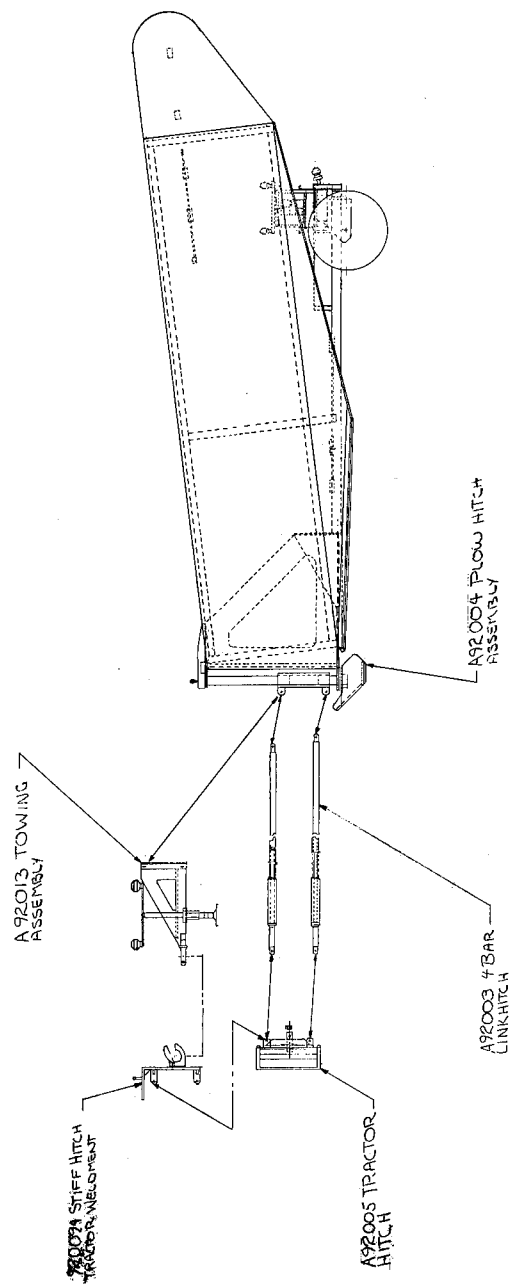
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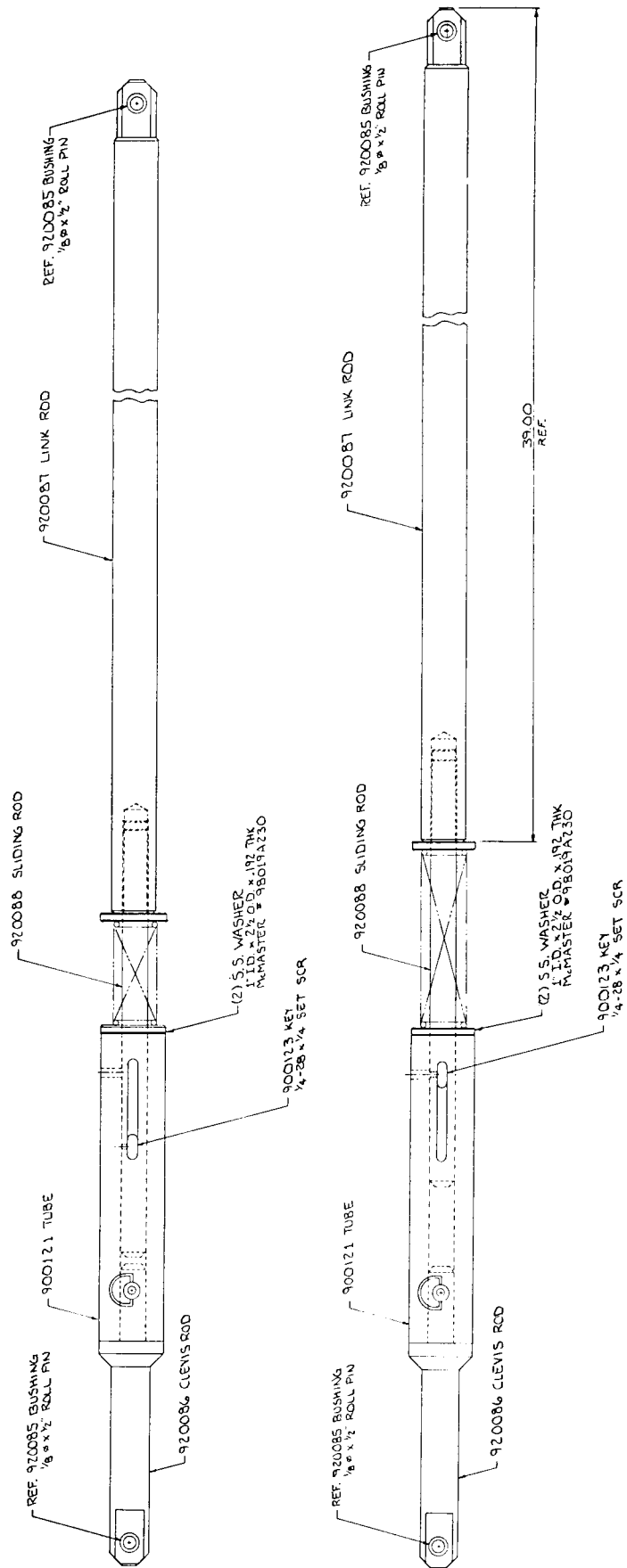
APPENDIX A: ASSEMBLY DRAWINGS OF THE FULL-SCALE PROTOTYPE DRAG PLOW

This appendix contains the current assembly drawings for the full-scale drag plow as available at the time of printing. These drawings do not necessarily correspond to the plow as tested in Alaska in 1992 and reflect design changes as mentioned in the body of this report. They are also not necessarily the final and complete set of drawings, as design modification of the plow is an ongoing process and additional design changes may be required based on user needs and experience gained from the 1993 field season.

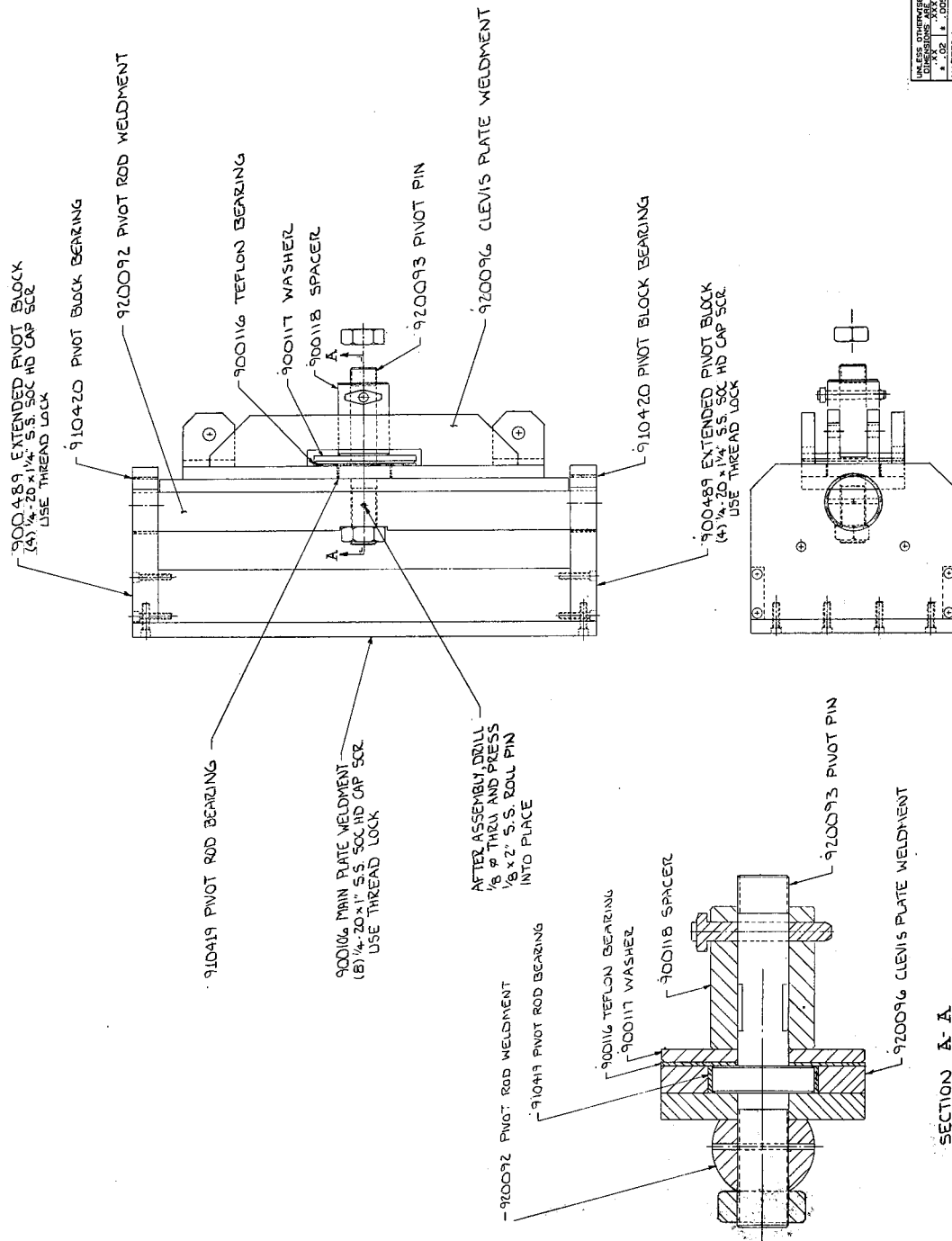
The first two pages contain overall illustrations of the major assemblies of the plow, the four-bar link towing mechanism and the plow. Subsequent drawings are of subassemblies of these major assemblies.



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES FRACTIONS DECIMALS TOLERANCES MATERIAL	PROJECT SUB DRG PLOW	U.S. ARMY-CG CRREL EMER-TED HAWTHORNE, N.H.
	PREPARED BY P. J. RICHMOND	DATE 3/23
DRAWING NO. 101	APPROVED BY C. J. LEE	NAME FINAL ASSEMBLY SIDE VIEW
	REVISIONS	
HEAT TREAT	NUMBER A93018	SCALE 1/4" = 1"
		SHEET 2 OF 2



U.S. ARMY-COE CRREL CONSTRUCTION RESEARCH & ENGINEERING LABORATORY WATKINS, N.H. 03095		4 BAR LINK HITCH NAME NUMBER A92003 SCALE 1/4" = 1"	
PROJECT FULL SCALE SUSV DRAG FLOW PHASE III PARTS LIST NUMBER 31 APPROVED DATE 10/13/13 DRAWN BY CHECKED BY REVISIONS		MATERIAL DIMENSIONS ARE IN INCHES 1/8" = 1/8" x 1/8" x 1/8" 1/4" = 1/4" x 1/4" x 1/4" 1/2" = 1/2" x 1/2" x 1/2" 3/4" = 3/4" x 3/4" x 3/4" 1" = 1" x 1" x 1" 1 1/2" = 1 1/2" x 1 1/2" x 1 1/2" 2" = 2" x 2" x 2" 3" = 3" x 3" x 3" 4" = 4" x 4" x 4" 6" = 6" x 6" x 6" 8" = 8" x 8" x 8" 10" = 10" x 10" x 10" 12" = 12" x 12" x 12" 14" = 14" x 14" x 14" 16" = 16" x 16" x 16" 18" = 18" x 18" x 18" 20" = 20" x 20" x 20" 24" = 24" x 24" x 24" 30" = 30" x 30" x 30" 36" = 36" x 36" x 36" 42" = 42" x 42" x 42" 48" = 48" x 48" x 48" 54" = 54" x 54" x 54" 60" = 60" x 60" x 60" 66" = 66" x 66" x 66" 72" = 72" x 72" x 72" 78" = 78" x 78" x 78" 84" = 84" x 84" x 84" 90" = 90" x 90" x 90" 96" = 96" x 96" x 96" 102" = 102" x 102" x 102" 108" = 108" x 108" x 108" 114" = 114" x 114" x 114" 120" = 120" x 120" x 120" 126" = 126" x 126" x 126" 132" = 132" x 132" x 132" 138" = 138" x 138" x 138" 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U.S. ARMY-CORREL ENGINEERING HANCOCK, N.H. 03048	
NAME TRACTOR HITCH	
NUMBER A92005	
SCALE HALF	
SHEET 1	
PROJECT SIZE SUSV DRAWING PART III	PREPARED BY 10/1/55
CHECKED BY 10/1/55	APPROVED BY 10/1/55
MATERIAL 10/1/55	10/1/55

REPORT DOCUMENTATION PAGE

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6. AUTHORS Paul W. Richmond and Michael R. Walsh					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Cold Regions Research and Engineering Laboratory 72 Lyme Road Hanover, New Hampshire 03755-1290				8. PERFORMING ORGANIZATION REPORT NUMBER CRREL Report 94-10	
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13. ABSTRACT (<i>Maximum 200 words</i>) Light Infantry Division elements require a system to allow them to conduct semi-autonomous operations and limited self-resupply with existing wheeled vehicles in snow deeper than 15 cm. Since many roads and trails will not have been kept open prior to deployment, truck-mounted plows (if available) would be ineffective. In most instances, heavy tracked vehicles, which can cause extensive environmental damage, are required to move deep snow. Over-snow vehicles can be equipped with front- or rear-mounted plow blades. But to adapt a plow to the U.S. Army's only over-snow vehicle, the small unit support vehicle (SUSV), would require major vehicular modifications. A towed plow assembly for the SUSV was proposed. To adapt the plow for this application, a unique four-bar parallel linkage towing assembly was developed, which bolts directly on to the SUSV's pintle hook mounting bracket. This assembly controls the pitch, and the plow geometry stabilizes the roll of an attached plow. The plow was constructed primarily of aluminum, has three plowing widths, and can be towed over the road (minimum width 2.3 m). This report describes the design, operation and results of field tests of the towing assembly and plow. The SUSV successfully towed the plow through deep (85 cm) unbonded snow, creating a path wide enough for a wheeled vehicle. In hard, dense, wind-blown snow the plow was less successful, requiring several passes to open a trail. No major failures occurred, although some minor problems were identified, and recommendations for design improvements are presented.					
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